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(54) DYNAMIC BALANCING IN WOBBLE DISK DEVICES

(71) I, ERNST BOSSHARD, of Waldistrasse 36, 8134 Adliswil, Switzerland, a Swiss citizen, do hereby declare the invention for which we pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statment:—

The present invention relates to a wobble disk device and to a method to balance dynamic forces arising in the operation of such a device.

Wobble disk devices may operate as motors having pressurized fluid applied to reciprocating pistons which react on an inclined disk or an inclined plate; or they may operate as pressure generators in which a pressure fluid is compressed by reciprocating pistons engaged by the wobble disk. "Wobble disk devices" as used in the present application are intended to encompass apparatus operating either in the motor, or in the compressor mode, as desired.

Various types of wobble disk apparatus (also known as swash-plate apparatus) are known. Typically, a wobble disk apparatus has a plurality of pistons operating in parallel, around a centre point, driven from a wobble or inclined disk. The rotary power can be applied either to a shaft passing into the housing, or to the housing of the machine, the centre point of the wobble disk being held stationary. The devices of this type are, therefore, quite versatile. They are, however, subject to vibrations which interfere with efficient operation thereof, so that they are primarily used for comparatively slowly operating pumps.

It is an aim of this invention, in one aspect thereof, to provide a wobble disk device, selectively operating in a desired mode, and selectively driven, or providing driving power, in which externally acting forces are effectively balanced, so that the device can operate at high speed.

Briefly, in the two main aspects of this invention respectively claimed in claim 1 and claim 3, the dynamic force arising in operation of the device and caused by reaction of the reciprocating elements on the wobble disk are balanced by generating dynamic balancing torques approximately equal and opposite to the dynamic reaction forces, the dynamic balancing torques being applied as balancing forces coaxially with respect to the drive shaft or centre of rotation of the device.

The device itself has balancing weights coupled to the drive shaft or other rotating element, for example attached to a hood or cup-like structure, to permit placement of the balancing weights at axially spaced position with respect to the shaft, preferably at opposite sides of an imaginary plane extending at right angles to the axis of rotation of the device and passing through the intersection between the axis of rotation of the wobble disk and the wobble axis (defined as an imaginary axis extending from the center of the wobble disk at right angles to the plane of inclination thereof).

Torques and other forces which cause vibration are then effectively counterbalanced or counteracted so that devices of this kind can operate, in accordance with the method, at high speed. Imbalances of second order are also effectively prevented.

The accompanying drawings, illustrate preferred embodiments of the invention, and wherein:

Figure 1 is a longitudinal sectional view through a wobble disk device;

Figure 2 shows an enlarged detail of the structure thereof;

Figure 3 is an enlarged schematic fragmentary cross-sectional view through a universal joint in the device;

Figure 4 is a highly schematic diagram illustrating the balancing of forces arising in operation of the device due to masses which are reciprocating;

Figure 5 is a highly schematic diagram

illustrating the balance of forces arising in operation of the device due to centrifugal force resulting from movement of the wobble disk; and

Figure 6 is a highly schematic longitudinal cross-sectional view, omitting all inessential components, having a rotating wobble disk for force equalization.

The device to be described can transform a reciprocating movement into rotary movement, or vice versa. It can operate as a piston-cylinder motor, for example as an internal combustion engine. It can also operate as a compressor or as a pump for fluids, particularly liquids, for example hydraulic pressure fluid.

In the description to be used hereinafter, and in the claims, reference will be made to a "shaft". Figures 1 and 6 illustrate this shaft, designated with reference numeral 23. This is the shaft which is either driven, if the device is to operate as a pump, for example, or from which rotary output is to be taken if, for example, compressed fluid is selectively admitted to the piston of the device, for example under control of slider valves. The relationship between fixed housing and shaft can be reversed, however, and since the housing, usually, is cylindrical, the term "shaft" as used herein shall be deemed to be that element which is rotated relative to a fixed frame, that is, is subject to centrifugal forces. The reversal of the relationship of movement between housing and shaft—whether the housing is fixed and the shaft rotates, or whether the shaft is fixed and the housing rotates, is a matter of choice and external design requirements.

Referring to the drawings, and specifically to Figures 1 to 3: A cylinder block 1 which is stationary, if shaft 23 rotates, has a plurality of pistons 2 located therein, arranged around the circumference of an imaginary cylinder, which can reciprocate in cylinders *9a* formed in the housing. Six pistons 2 are provided in the example illustrated, although any number can be used. The cylinder block 1 is of circular cross-section and is securely connected to a base or frame 29. Alternatively, the housing 1 could rotate and shaft 23 could be connected to the base or frame 29. A cylinder head 31 is located at the end of the cylinder block 1, cylinder head 31 being formed with valves (not shown) which can be conventional. These valves may, for example, be slider valves.

Each one of the pistons is linked to a piston rod 3 by a spherical joint 4. The other end of piston rod 3 is formed with a ball socket 8 which engages around a ball 7. Ball 7 has a pin extension. The edge of the socket 8 is peened over the ball 7 so that ball 7 is received in the socket, and held therein, while still permitting movement with three degrees of freedom. The balls 7 are connected to cylindrical attachment bolts 11 which are screwed in suitable tapped openings formed in wobble disk 12. Each piston rod 3 thus connects the wobble disk 12 with a respective piston 2 over a double-joint which is free to move with three degrees of movement, in a force-transmitting double-jointed link arrangement.

The wobble disk 12 is formed with a hub 14, into which a bushing 19 is removably inserted (see Figure 2). Bushing 19 passes through a bearing 9 which is fixedly secured in a disk 22. Disk 22 is attached to shaft 23. The bearing 9 is eccentrically located on disk 22 with respect to the central axis x of shaft 23. A screw 13 passes through bushing 19 and engages the hub 14 of wobble disk 12 with a tapped end on the bolt 13. The wobble disk axis y makes an angle of from about 15 to 24°, preferably about 22° with respect to the axis x of shaft 23. The bearing 9 is fixedly inclined with respect to disk 22. During rotation of disk 22, the wobble axis y forms the generatrix of a cone. The wobble disk 12 thus can rotate relatively with respect to disk 22 about the wobble axis y. Bearing 9 accommodates relative movement between the disk 22 and the wobble disk 12 and transmits drive between the disks 12 and 22. Bearing 9, which is shown as a sleeve bearing, may also be a rolling bearing, such as a roller pin or ball bearing; the relative movement between disk 22 and wobble disk 12 can also be transferred to a bearing located in hub 14.

Shaft 23, coupled to the disk 22, is either the drive shaft for the device or the take-off shaft, depending upon whether the device operates as a motor, or a pump or compressor. Shaft 23 is journalled in two bearings 24, axially spaced from each other by a bearing sleeve and secured in a bearing holder 25, in turn secured to the base or housing 29. The shaft 23 and the bores of the cylinders 9a of the piston 2 are all parallel. It would also be possible to make the cylinder bores slightly divergent or converging. The geometrical axis x of shaft 23 and the wobble axis y intersect at a point P which is located between the bearings 24 and cylinder block 1.

The shaft 23 and the disk 22 which is rotatably secured thereto, can be coupled to or uncoupled from the wobble disk 12 by releasing screw 13. Normally, the disks 12 and 22 are coupled in driving relationship. The housing 25 for the bearing is formed with a tapped opening 30, closed off by a plug 32. The opening 30, and consequently the plug 32, are of such size that pin 13, and preferably also sleeve 19, can be removed through the opening 30 for adjustment,

replacement and/or lubrication. The sleeve 19 is subject to stress since it provides for rotary force transfer between the wobble disk 12 and the disk 22, providing for the eccentric coupling of the wobble disk to shaft 23.

A universal joint 20 is located between the wobble disk 12 and the cylinder block 1 or the housing, respectively. Universal joint 20 is a force transfer joint which has the purpose of preventing relative rotation of the wobble disk 12 with respect to the cylinder block 1, while at the same time permitting the universal wobble movement of the wobble disk 12. It also accepts axial forces and transfers them to the housing 1. Upon rotation of shaft 23, pistons 2 reciprocate back-and-forth.

Universal joint 20 must be capable of accepting movement in two transverse planes, that is, to have two directions of freedom, in the form of a gimbal. It has two relatively perpendicular arranged pivot axes 17, 18 connected by a coupling ring or gimbal ring 15.

One pair of coupling pins 18, located transversely with respect to each other, and as best seen in Figure 3, engages with the wobble disk 12. The other shaft 17 is held in a central stationary projection or bolt 16. Bolt 16 extends coaxially with respect to the longitudinal axis x and is securely fixedly connected to the cylinder block 1, or is unitary therewith. The coupling ring 15 is centered on the pins 17, 18 by means of centering rings 21, slipped over the respective pins (see Figure 3). The joint 20 is located in a central recess of the wobble disk 12 in order to decrease the axial length of the device. Preferably, the theoretical centre of gravity, and also the centre of movement of joint 20, is congruent with the point P and thus is congruent with the intersection of the geometrical axis x of the shaft 23 and the geometrical wobble disk axis y. The centre point of all the ball joints 7 which are connected to the piston rod 3 and to the wobble disk 12 are in a common plane Z, which extends at right angles to the wobble axis y, and likewise passes through the point P, or is only slightly spaced from point P. These relationships permit minimum angular deflection of the piston rods 3. The universal joint 20 locates the wobble disk 12 in radial as well as in axial direction and accepts forces acting on the wobble disk 12. Since the universal joint 20 is centrally within the ring of the piston rods 3, it is possible to construct this joint in a compact yet sturdy manner. Friction losses within the universal joint 20 are small since the relative movement between the rings and attachment points thereof does not extend to full rotation, but only over comparatively small angular pivoting distances.

Rapid rotation of shaft 23 causes reciprocating forces to arise in the wobble disk 12 which must be compensated if the device is to operate without excessive vibration. To provide for compensation, a tubular element 27 is secured to the disk 22, extending axially and surrounding the wobble disk 12. The tubular element 27, together with disk 22, forms a hood 26 or cup-shaped element extending over and surrounding or encompassing the wobble disk 12 therein. This hood 26 functions as a carrier for counter or balance weights which are so selected with respect to position and mass that they compensate the forces arising in operation of the device due to reciprocation of the piston, and rotation of the wobble disk. The hood or cup-shaped element 26 can be made to be comparatively heavy to function additionally as a flywheel.

Two types of forces act on the wobble disk which, for purposes of analysis, will be considered separately. Of course, these forces act on the disk simultaneously when the device is operated.

Figure 4 diagrammatically and highly schematically illustrates the forces acting on wobble disk 12 as a consequence of the reciprocating masses in the device, essentially the piston, piston rod and the connecting links connected thereto, as well as the associated sector-shaped portion of the wobble disk 12. These forces are shown in Figure 4 as A and B, acting parallel with the direction of the axis x, that is, in the direction of the longitudinal axis of the device, of the pistons, and of the shaft 23. No acceleration or deceleration forces act on the respective piston at the end positions and hence on the wobble disk 12. The acceleration and deceleration forces are also zero in the centre of the piston stroke since the piston accelerates in one half of its stroke and decelerates in the other half; exactly at the centre there is neither acceleration nor deceleration.

Let it be assumed that the wobble disk 12, as shown in Figure 4 is in one of its extreme positions. Only a single piston will be considered in the discussion that follows. First, the acceleration and deceleration forces will be considered which are applied by movement of the piston 2a and the other reciprocating parts on the wobble disk 12 as the wobble disk 12 moves in a semi-circle, starting with 90° in advance of the extreme position shown in Figure 4, and terminating 90° after this position.

In the first quarter revolution, piston 2*a* exerts an increasing and then decreasing retardation force on the wobble disk. In the second quarter revolution, first an

increasing and then a decreasing acceleration force acts on the wobble disk 12 due to operation of the piston 2*a*. Both forces act in the direction of arrow A. The diametrically opposite piston 2*b*, with its reciprocating part, exerts exactly opposite forces on the wobble disk, the acceleration and deceleration forces with respect to the wobble disk 12 being effective in the direction of the arrow B.

As can readily be seen, the forces A and B exert a torque in the direction of the arrow C on the wobble disk 12. It is an aim of the present invention to compensate for this torque by applying a counter-torque. This is obtained by locating balancing weights or counterweights 28, 34 on the cylindrical, tubular extension 27 on hood 26. The balancing weights 28, 34 are axially offset with respect to each other. Upon rotation of the hood 26, centrifugal forces shown by arrows D and E will result. Due to the axial distance of the counterweights 28, 34 from each other, a torque shown by arrow F will result, counter the direction of torque C. The counterweights 28, 34 are so selected and located that the counter torque F will balance the torque C due to the reciprocating movement of the pistons. The counter-weights 28, 34 are preferably so located on the hood 26 that the centre-line or resultant of the torque goes through the point P. In the extreme position of wobble disk 12, as shown in Figure 4, the weight 34 as well as the upper half of the wobble disk 12 are on the one side of a plane T passing through point P and at right angles to axis x; the other counter-weight 28, as well as the other half of the wobble disk 12, is at the other side of this imaginary transverse plane. The effective overall force of the reciprocating masses of each half of the piston stroke is, effectively, located at a radial distance from the axis x which is less than the actual radial distance of the pistons 2 from the axis x due to the varying effect of the forces which rise from zero and then drop to zero during one revolution.

Figure 5 illustrates the effect of centrifugal forces due to the operation of the wobble disk itself, and its balancing and compensation.

Let is be assumed that a transverse plane Z passes transversely through the wobble disk 12. This plane Z extends at right angles to the wobble axis y and subdivides the wobble disk 12 in a first portion 12*a* and a second portion 12*b*. The stationary point P is the intersection of the axes x and y. Upon rotation of the shaft 23, disk portion 12*a* has a centrifugal force G act thereon, which is active at the centre of gravity M, or central portion of the disk portion 12*a*, since this disk portion carries out a circular movement with radius a about axis x. The centrifugal force G can be balanced by an equal and opposite force K, acting in the same plane. A balance mass 38 is applied to the hood 26 which, considering the different radial distance of the point of action of the forces of G and K from the axis x, is to be suitably dimensioned.

The second wobble disk portion 12*b* can be similarly considered; a centrifugal force H acts at the centre of gravity N on the disk portion 12*b*. The centre of gravity M and N are at opposite sides of the transverse plane Z. Forces G and H are effective in respectively opposite directions. The centre of gravity N of the portion 12*b* rotates about a circle with radius b. The centrifugal force H of the second disk portion 12*b* can be balanced by providing a counter force J generated, for example, by a balance weight 39 secured to the hood 26. Balance weight 39 is located in the same plane as H and generates an equal and opposite centrifugal force, so that the respective centrifugal forces acting on the wobble disk are mutually balanced.

The balance weights 34 (Fig. 4) and 39 on the one hand, and 28 (Fig. 4) and 38 (Fig. 5) on the other, are at diametrically opposite sides. Thus, those balance weights which are always at one side can be combined to provide one combined, resulting, overall balance weight, balancing both forces, that is, the forces due to reciprocating movement of the pistons as well as the forces arising due to centrifugal force of the wobble disk, in two diametrically located elements outwardly of the wobble disk.

The effective weight of the portion of the wobble disk 12*b* can be made small with respect to the portion of the wobble disk 12*a* so that, for practical purposes, it can be neglected. Thus, it is only necessary to combine the mass of weight 38 (Figure 5) with the mass of weight 28 (Figure 4), the mass of weight 39 (Figure 5) being practically negligible.

The illustration of counter-weights 28, 34; 38, 39 as attached weights to the hood 26 is shown in Figures 4 and 5 as separate elements for purposes of illustration and explanation. The same effect can be obtained by diametrically oppositely located negative compensating masses, for example by milling out portions of the hood 26 to provide for a compensating area of lesser mass. Thus, as referred to herein "balancing forces or torques" and "balancing masses" should be understood to be both positive as well as negative values.

Shaft 23 and hood 26 can be formed as one single integral element; or shaft 23 and disk 22 can be formed as a single crank arrangement in which the shaft 23 has a

right-angle crank attachment extending in the direction of the wobble axis y to provide for rotary movement of the bearing 9.

In the embodiment of Figure 1, the wobble disk 12 does not rotate. Various types of wobble disk devices have rotating wobble disks. Figure 6 illustrates an arrangement in which a rotating wobble disk 42 is secured to shaft 23. The piston rods 3 are fixed to the pistons 2 and engage against the wobble disk 42 with a rounded or ball-shaped end thereof. The wobble disk 42 is dynamically balanced by means of balance weights 44, 45 which correspond to the weights 38, 39. The hood 26 has weights 28, 34 secured thereto in order to balance the reciprocating forces due to reciprocation of the pistons 2, as explained in connection with Figure 4.

As explained, rotation of shaft 23 and stationary maintenance of cylinder block 1 can be dynamically reversed, so that shaft 23 is fixed and the cylinder block 1, or the housing, respectively, rotates. If this arrangement is selected, the weights are then secured to the housing, for example to the interior thereof, to balance centrifugal forces as well as reciprocating forces in operation of the device. For simplicity, the term "shaft" has been retained in the claims as the rotating element since, if the housing rotates, it will be cylindrical and thus analogous to a "shaft". The term "shaft" in the claims, therefore, is to be deemed to relate to the rotating portion of the apparatus in its respective context.

WHAT I CLAIM IS:—

1. A method of balancing dynamic reaction torques developed in operation of a wobble disk device which includes a wobble disk, rotating elements including a shaft, the wobble disk being positioned in a plane inclined with respect to the axis of rotation of the shaft and reciprocating elements including at least one reciprocating piston and coupling means in engagement with the wobble disk;

the said method comprising the steps of: (a) generating dynamic balancing torques at least substantially equal and opposite to the dynamic torques developed upon movement of said rotating elements; and (b) generating dynamic balancing torques at least substantially equal and opposite to the dynamic torques developed upon movement of said reciprocating elements by applying to the shaft rotating masses rotating coaxially with the shaft outwardly of the wobble disk.

2. A method according to claim 1, wherein the wobble disk in operation generates a dynamic centrifugally generated imbalance torque, and in step (a) the balancing torques are generated by coupling rotating balancing masses to the shaft which have a mass and distance from the shaft to balance said centrifugally generated torque, all rotating masses being outwardly of the wobble disk, and applying the balance masses on both sides of an imaginary plane passing through the point of intersection of the wobble axis and the axis of rotation of the shaft.

3. A wobble disk device having:

a wobble disk;

rotary elements and a shaft coupled to said wobble disk;

reciprocating elements including at least one reciprocating piston and coupling means in engagement with the wobble disk;

and balance mass means comprising means to balance dynamic torques arising in the operation of the device caused by reaction of the rotary elements on the wobble disk, and rotating means to balance dynamic torques arising in the operation of the device caused by reaction of the reciprocating elements, the rotating means being coupled to the shaft and rotating in use coaxially therewith outwardly of the wobble disk, the balance mass means generating in use a balancing dynamic torque which balances the dynamic reaction torques arising in operation of the device as a consequence of dynamic reaction forces resulting from reciprocation of said reciprocating elements and rotation of said rotary elements.

4. A device according to claim 3, wherein said balance mass means comprise centrifugal force balance mass means acting on opposite sides of an imaginary plane which passes through the intersection of the wobble axis and the axis of rotation of the shaft and which is perpendicular to the axis of rotation of the shaft.

5. A device according to claim 3, wherein said balance mass means comprises centrifugal force balance mass means located to balance centrifugal forces acting on the wobble disk in operation of the device, said centrifugal balance masses acting at least substantially in the planes passing through the centres of gravity of those portions of the wobble disk lying at opposite sides of an imaginary plane parallel to the plane of the wobble disk and passing through the intersection of the wobble axis and the axis of rotation of the shaft, wherein the wobble axis is defined as an imaginary axis extending from the centre of the wobble disk at right angles to the plane of inclination thereof.

6. A device according to claim 3, wherein the rotating means include a cup-shaped or hood-shaped element extending from and coupled to the shaft and having an axial length extending at least at both sides of an

imaginary plane passing through the axis of the shaft and the intersection of the wobble axis therewith, the balance mass means being located at diametrically opposite positions, and axially offset with respect to each other;

and wherein said wobble axis is defined as an imaginary axis extending from the centre of the wobble disk at right angles to the plane of inclination thereof.

7. A device according to any of claims 3 to 6 wherein said balance mass means are located at opposite sides of the imaginary plane passing through the intersection between the wobble axis and the axis of rotation of the shaft.

8. A device according to claim 7, wherein the wobble disk defines an imaginary wobble disk plane extending at right angles to the wobble axis and passing through said intersection between the wobble axis and the axis of rotation of the shaft, the wobble disk plane dividing said wobble disk in a first wobble disk portion and a second wobble disk portion;

and wherein the balance mass means includes a balance mass each, associated with said respective wobble disk portions, located at diametrically opposite positions on the rotary elements and in the plane of the centre of gravity of the respective wobble disk portions.

9. A device according to claim 8, wherein said balance mass means comprise weight elements located at respectively opposite sides of said cup-shaped or hood-shaped element and having a mass and position balancing the combined effects of the forces due to the reciprocating elements and the rotary elements of the device.

10. A device according to any of claims 3 to 9, wherein said device comprises a fixed structure;

and a universal joint secured to said fixed structure and coupling the wobble disk thereto, the theoretical centre of movement of said universal joint coinciding with the intersection of the axis of rotation of the shaft and of the wobble disk axis,

wherein the wobble disk axis is defined as an imaginary axis extending from the centre of the wobble disk at right angles to the plane of inclination thereof;

and means coupled to the shaft and eccentrically with respect thereto engaging the wobble disk along said wobble axis.

11. A device according to any of claims 3 to 10, further comprising ball-and-socket connecting joints connecting the pistons and the wobble disk.

12. A device according to any claims 3 to 12, wherein the wobble axis, defined as an imaginary axis extending from the center of the wobble disk at right angles to the plane of the inclination thereof and the axis of rotation of the shaft include an angle of between about 15 to 24°.

13. A device according to claim 12, wherein said angle is about 22°.

14. A device according to claim 10 or any claim appendant thereto, wherein said wobble disk is formed with an internal recess, said internal recess surrounding said universal joint;

and wherein the reciprocating elements include pistons and piston wobble-disk connecting means located in a ring surrounding said universal joint.

15. A device according to claim 10 or any claim appendant thereto wherein said universal joint comprises a gimbal-type suspension having one shaft coupled with said fixed structure, and another shaft, extending at right angle to said one shaft, coupled to the wobble disk.

16. A device according to any of claims 3 to 15, further including severable connection means coupling the wobble disk and the shaft and establishing fixed relative position of the shaft and the wobble disk upon severing of said connection means.

17. A device according to claim 16, further including a housing surrounding said rotating and reciprocating elements, said housing being formed with an opening at an end face thereof, the opening being larger than the severable portion of said severable connection means and positioned to permit access to said severable connection means to permit severing of said connection means, and removal of the elements thereof.

18. A device according to claim 17, wherein the shaft is formed with an eccentrically extending portion;

and said severable connection means includes a bearing sleeve engageable with said eccentric portion and said wobble disk, said sleeve providing for force and movement transfer connection between said eccentric portion and said wobble disk;

and means securing said sleeve in position on said eccentric means and said wobble disk.

19. A method of balancing dynamic reaction torques in wobble disk devices substantially as herein described with

reference to and as shown in Figures 1 to 5 or Figure 6 of the accompanying drawings.

20. A wobble disk device substantially as herein described with reference to and as shown in Figures 1 to 5 or Figure 6 of the accompanying drawings.

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5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

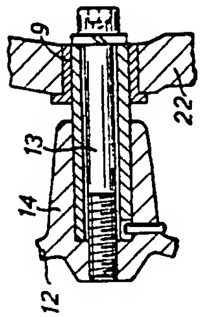

Fig. 2

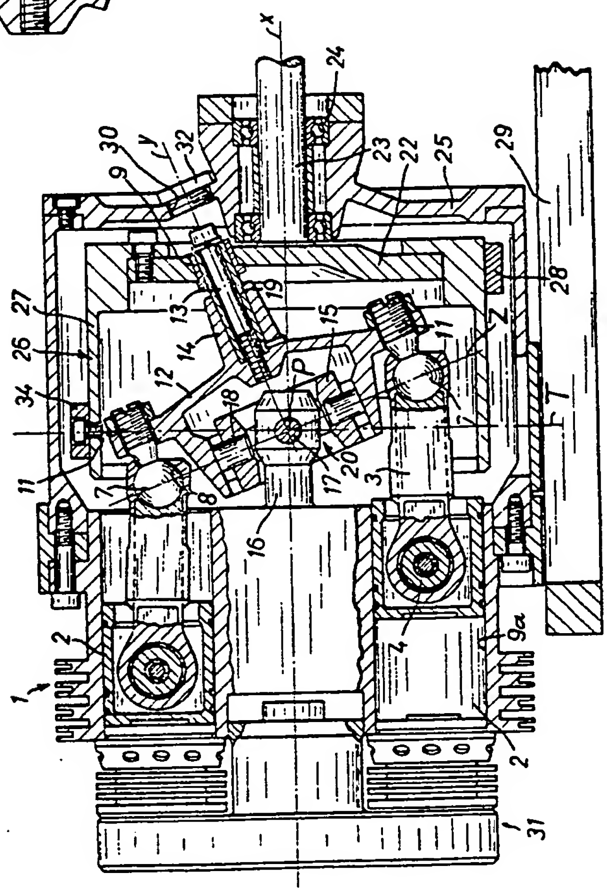

Fig. 1

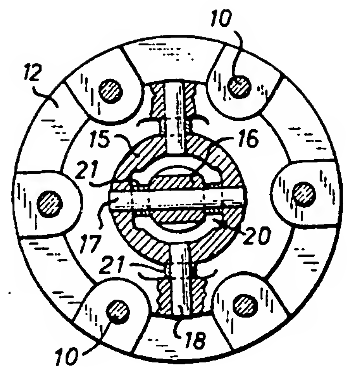

Fig. 3

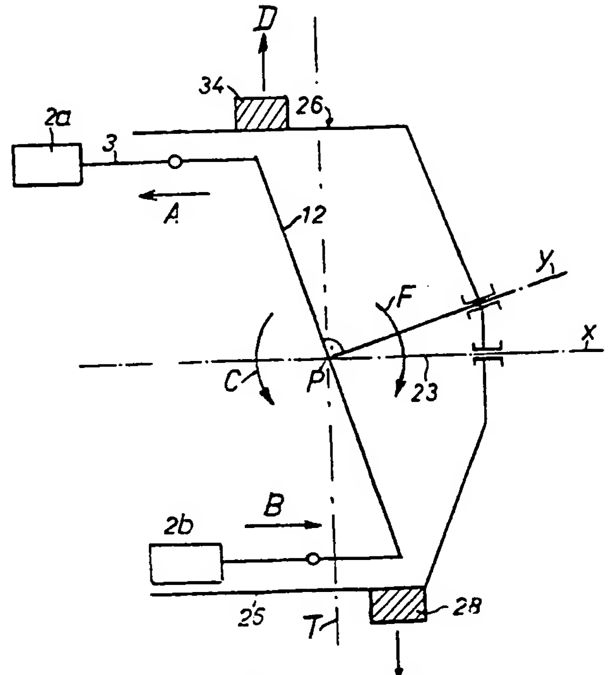

Fig. 4

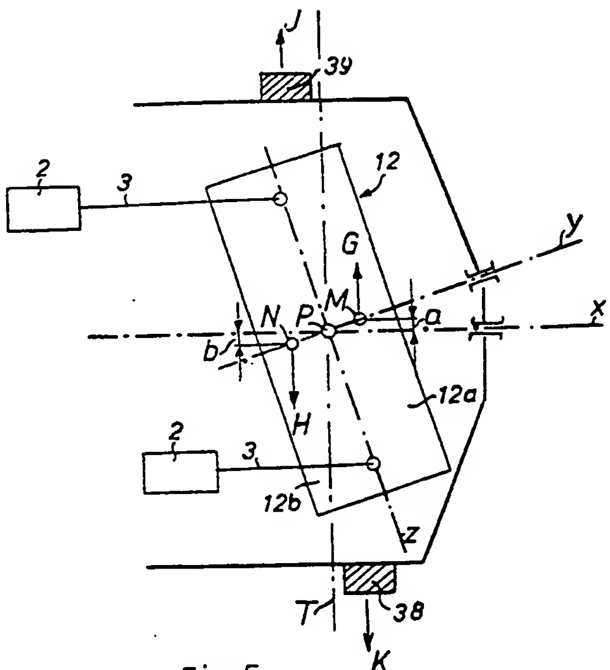

Fig. 5

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Sheet 5

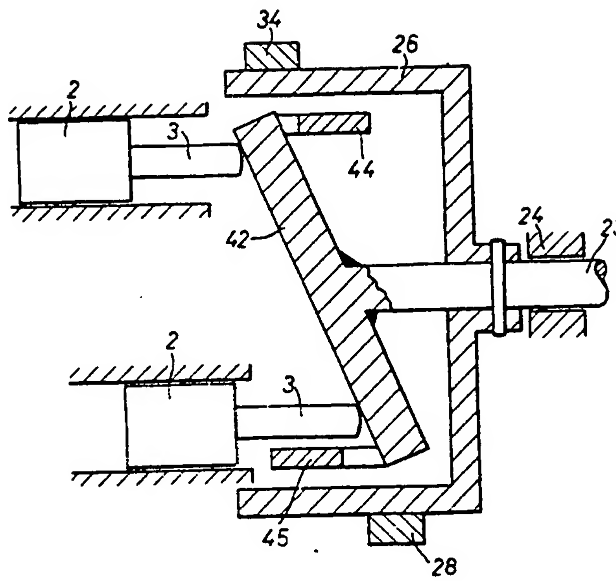

Fig. 6